

### Accelerometer Shock Calibration

S. Richter, P.S. Kaiker, and G.S. Nusholtz

#### ABSTRACT

Due to changes in an accelerometer over its life as well as other factors, the output voltage time-history of any given accelerometer for a given input acceleration time-history may change. Therefore, it is necessary to periodically check the accelerometer in order to maintain an acceptable level of accuracy. This paper presents a procedure to check, and in a limited sense, to calibrate the accelerometers used in biomechanics impact experiments. The device introduced in this paper is a "shock table" which permits a quick check of an accelerometer's output over a wide range of input accelerations.

#### INTRODUCTION

In order to calibrate or check an accelerometer, it is necessary to apply a known acceleration and then record the resulting output voltage. There have been two devices commonly used to apply an input acceleration to an accelerometer are the **spin platform** and the **rate table**. In spin calibration, an accelerometer is mounted in a cylinder which is then rotated at a known velocity. This process produces a constant acceleration which can be determined from the velocity and spin radius. In rate table calibration, an accelerometer is mounted near an accelerometer traceable to the National Bureau of Standards (NBS) on a platform which vibrates up and down at a known frequency. Because the NBS accelerometer records the acceleration of the table at each frequency, it provides the expected amount of acceleration at a given frequency for the accelerometer being calibrated.

However, neither of these methods calibrates an accelerometer using an acceleration time-history similar to that seen in the impact laboratory. When using spin calibration, it is only possible to obtain an output signal for one acceleration value at a time for a given frequency. Thus, in order to obtain a profile of the accelerometer's output over a wide range of accelerations, it is necessary to run the spin calibrator at several different velocities. Although rate table calibration provides a dynamic environment in which the table may be swept through a range of oscillations, it still does not approximate the actual time-histories obtained in impact experiments.

In addition, neither of these methods addresses one of the errors commonly seen in an accelerometer signal. This error is detected when the signal is integrated in order to determine the velocity and displacement.

Therefore, a method of calibration that would check the accelerometer by examining the integrated signal as well as produce a signal that would resemble the actual experimental acceleration time-history was needed. To accomplish this task, a shock calibration procedure was developed. The procedure allows us to obtain an accelerometer's output over a wide range of shock input accelerations in a form resembling the output from an impact test and examine the integrated signal.

**Shock Calibration** - The shock table calibration device consists of a vertical "dashpot" with a platform at the top of a threaded "plunger rod," a magnetic pickup probe, and a calibrated NBS accelerometer (See Figure 1). The NBS accelerometer and the accelerometer to be tested are mounted on the platform.

The platform and threaded plunger rod are accelerated downward by the forces of gravity and three "bungi cords." As the platform and plunger rod reach the bottom of the rod's stroke, the tip of the rod enters a hydraulic cylinder which causes the platform-plunger rod to rapidly accelerate. In order to eliminate rebound or "bounce" of the platform-plunger rod, channels were cut into the tip of the plunger rod to allow hydraulic fluid to flow past the tip. An out-flow tube directs fluid out of the cylinder and up to a point in the guide tube above the plunger tip, where it drains back into the cylinder. The plunger rod consists of a 2.5 cm diameter steel tube with eight threads per centimeter cut into its surface. As the platform-plunger rod begins to fall, there is a low level acceleration (5-20 g's). As it continues to accelerate downward, the velocity increases until the tip of the plunger rod enters the hydraulic cylinder, at which point a high acceleration between 20 to 500 g's occurs. The low level acceleration lasts from 100 to 300 milliseconds, while the high level acceleration lasts between 1 to 50 milliseconds. By varying the platform-plunger rod drop height, the stiffness of the bungi cords, and the amount and type of fluid in the hydraulic cylinder, it is possible to subject an accelerometer to a wide range of impact accelerations.

A digital linear displacement transducer, consisting of a magnetic pickup probe recording the threaded plunger-rod gradations, is mounted on the shock calibrator at the top of the guide tube. This transducer generates a voltage spike each time a thread on the plunger-rod passes the probe. Since the number of threads per centimeter is known, the voltage spikes provide a method for determining the plunger-rod position at each point in time. A software procedure computes displacement, velocity and acceleration from the data provided by the digital linear displacement transducer.

Shock calibration not only provides the ability to compare an accelerometer's output with a known acceleration (i.e., the NBS signal), but also a quick "check" over the range of input accelerations that we see in actual impact experiments. Figure 2 shows the accelerometer output for a typical thoracic impact test. Figures 3-5 show the accelerometer output for two accelerometers that were calibrated with shock calibration for the high acceleration levels.

The advantages of the shock calibration procedure include: 1) it is possible to check an accelerometer for discontinuities (i.e., fall out), 2) it is possible to check an accelerometer for intermittency (i.e., consistency), and 3) the NBS standard signal is not required for computation of velocity or examination of the integrated acceleration signal. The calibration procedure's primary disadvantage is that the digital linear displacement transducer signal cannot be reliably double-differentiated to the precision needed for calibration of accelerometers because the threaded plunger-rod does not have enough threads. We believe that a similar shock calibrator could be constructed with more threads on the plunger-rod that would permit reliable double-differentiation of the digital linear displacement transducer's signal.

Analysis of Shock Calibrations - The output from some typical accelerometer "checks" (See Figures 3-5) illustrate the ability of shock calibration to simulate acceleration time-histories similar to those seen in biomechanics impact experiments (See Figure 2). Figures 3 and 4 show that the integrated acceleration signal of a Kistler 8694 accelerometer is in good agreement with the velocity obtained from the digital linear displacement transducer, particularly at the end of the integration.

However, as we mentioned earlier, one of the "weak" points of this type of calibration is that computation of the data from the digital linear displacement transducer does not give an accurate reproduction of the acceleration signal. The acceleration signal computed from the digital linear displacement transducer data varies considerably from the accelerometer signals. Not only is the peak acceleration value computed from the digital linear displacement transducer data considerably less than the actual value, it can occur later than the peak of the accelerometer signals as shown in Figure 5 and as indicated by the phase lag between the two velocities near peak acceleration in Figures 3 and 4. That is, the acceleration signal computed from the digital linear displacement transducer data "lags" the accelerometer signal by about 5 milliseconds. Although the algorithm used to compute simultaneously acceleration, displacement and velocity from the digital linear displacement transducer data produces a more accurate acceleration signal than many existing methods, the diminishing of the high frequency component of the signal and the phase lag render the digital linear displacement transducer's measurements limited as a method for **accurately calibrating** accelerometers unless an NBS standard accelerometer is used in conjunction with it. The error in the acceleration computed from the output of the digital linear displacement transducer seems to be the result of two factors; the sampling rate and the gradation of the plunger rod.

We estimate that in order to substantially reduce the error in the acceleration computed from the output of the digital linear displacement transducer, it would be necessary to increase the number of gradations on the plunger rod by a factor of ten, from 8 to 80 threads per centimeter. In conjunction with this change, the sampling rate of 30 KHz would also have to be increased by a factor of ten, from 30 to 300 KHz. The changes necessary to reduce the error in the acceleration computed from the output of the digital linear displacement transducer to an acceptable level pose some difficult problems. First, 80 gradations per centimeter would mean an extremely fine thread size. Even if the fine thread size could be achieved, the magnetic pick-up probe would need a very high resolution capability, and tolerances throughout the system would also need to be extremely small.

To get around this problem without having to rebuild the shock calibration device, the digital linear displacement transducer signal is singly differentiated to produce the velocity, which is compared to the integrated acceleration signal. This technique also produces a velocity profile. In so doing, the error introduced by the sampling rate and the algorithm which is used to compute simultaneously displacement, acceleration, and velocity from the output of the digital displacement transducer is minimized. Figures 3 and 4 show the integrated acceleration signal and the singly-differentiated digital linear displacement transducer signal, which are identical at both the beginning and end of the signals.

Differences in the signal near the center are relatively small. Thus, this method of signal analysis allows the limited "calibration" of a given accelerometer with a reasonable measure of accuracy.

### Acknowledgements

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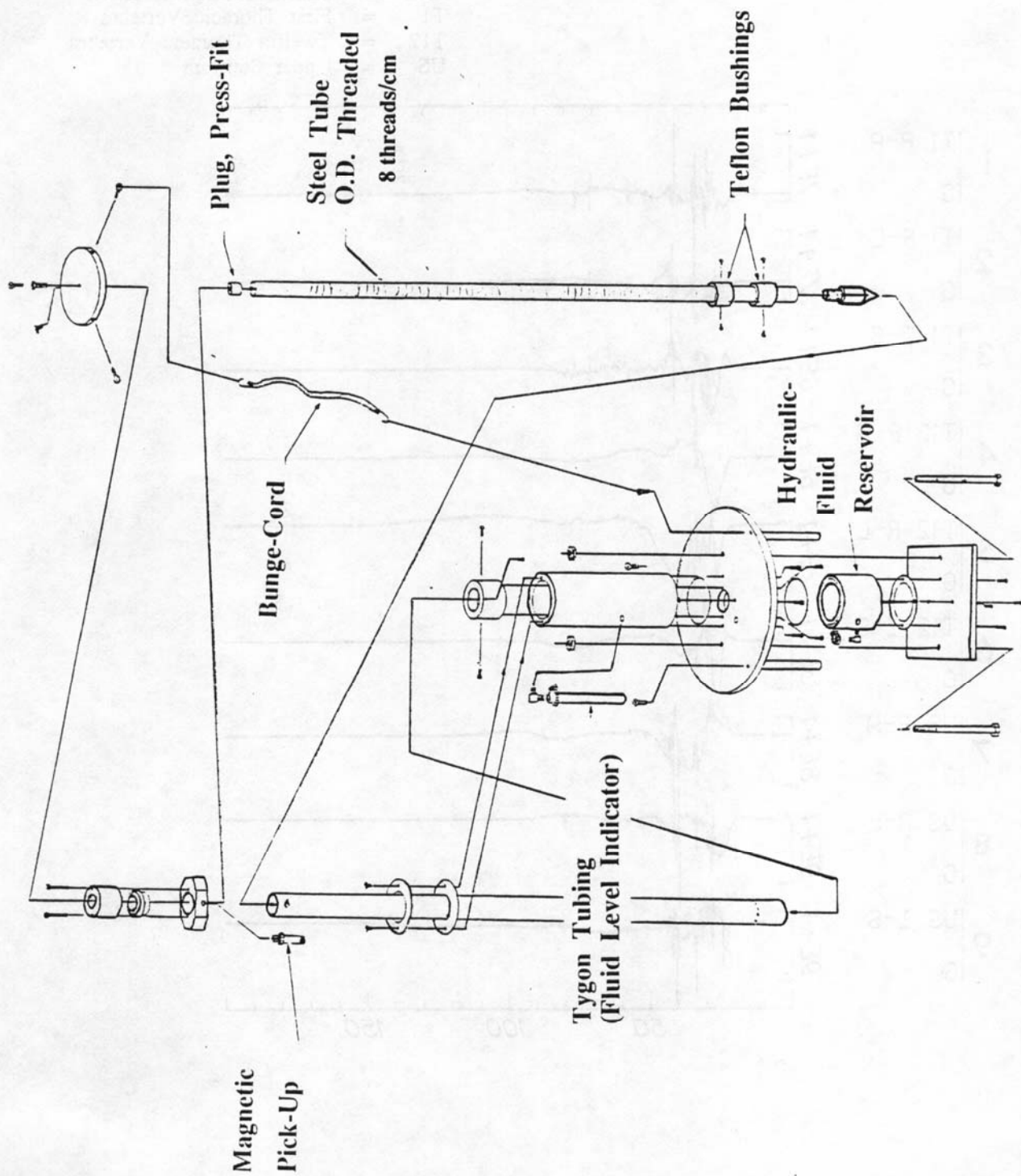


Figure 1. Accelerometer Shock Calibration Device (Digital Linear Displacement Transducer)

# KEY

PA = posterior-anterior direction  
 RL = right-left direction  
 IS = inferior-superior direction  
 T1 = First Thoracic Vertebra  
 T12 = Twelfth Thoracic Vertebra  
 US = Upper Sternum

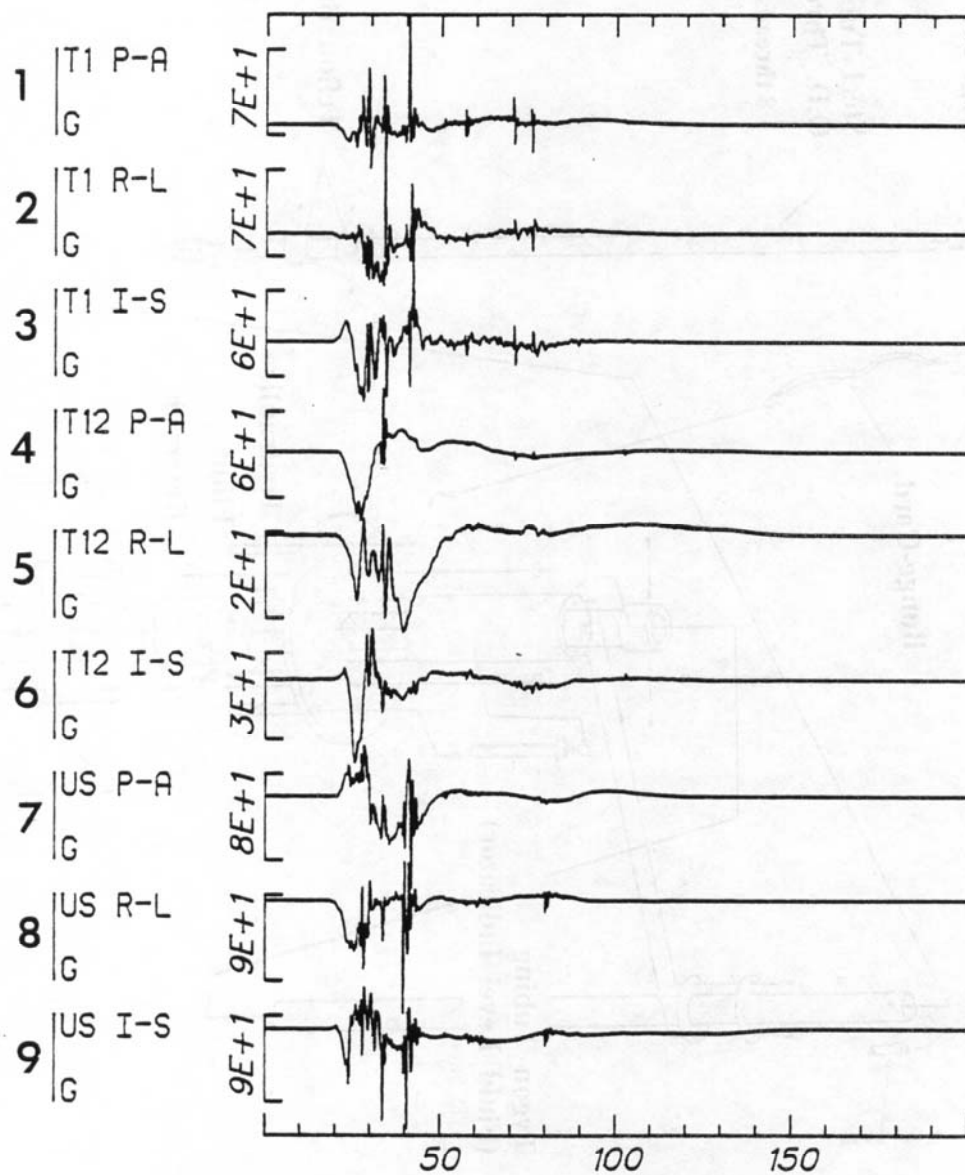


Figure 2. Laboratory Accelerometer Output for a Typical Thoracic Impact

# ACCELEROMETER SHOCK CALIBRATION

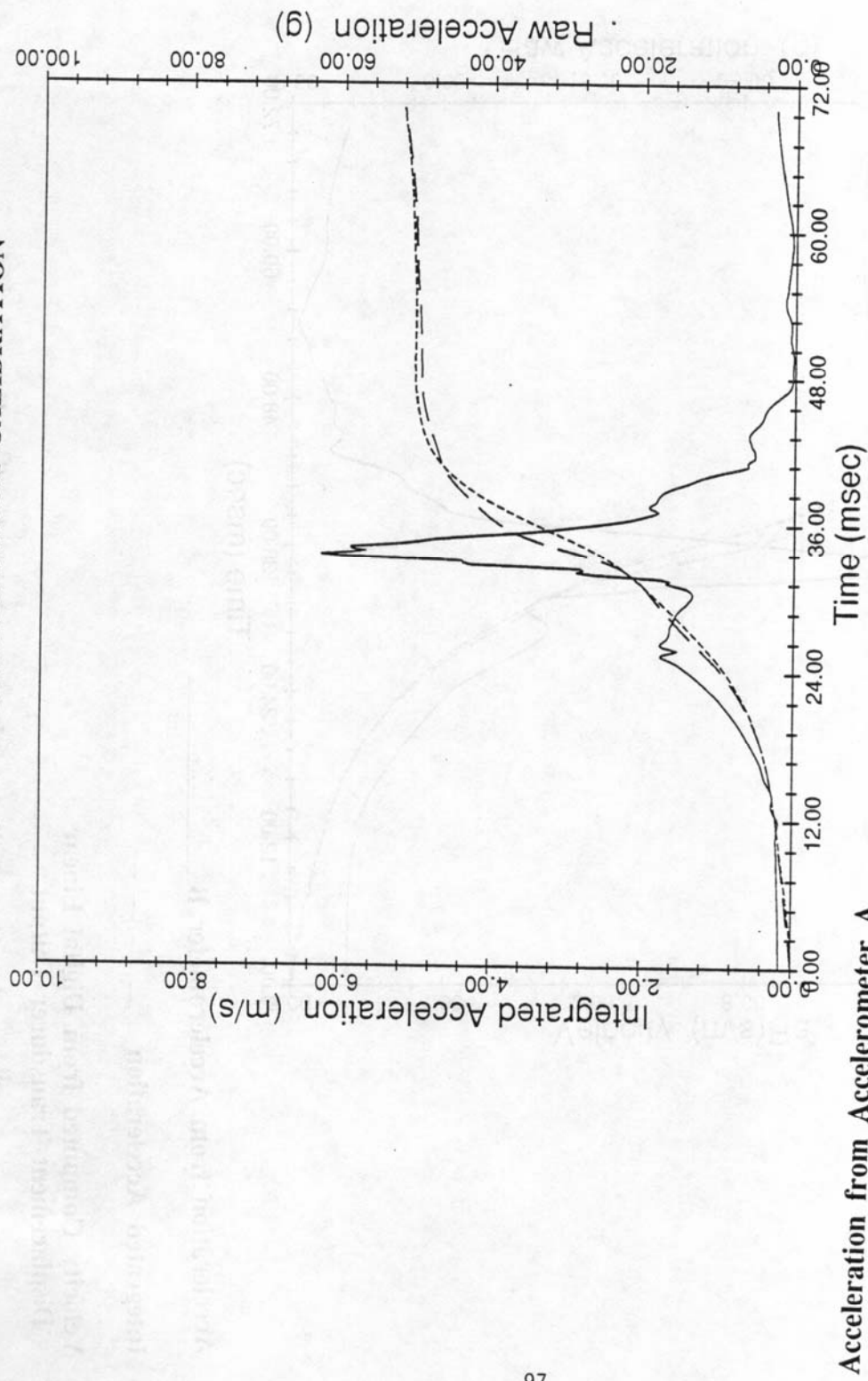
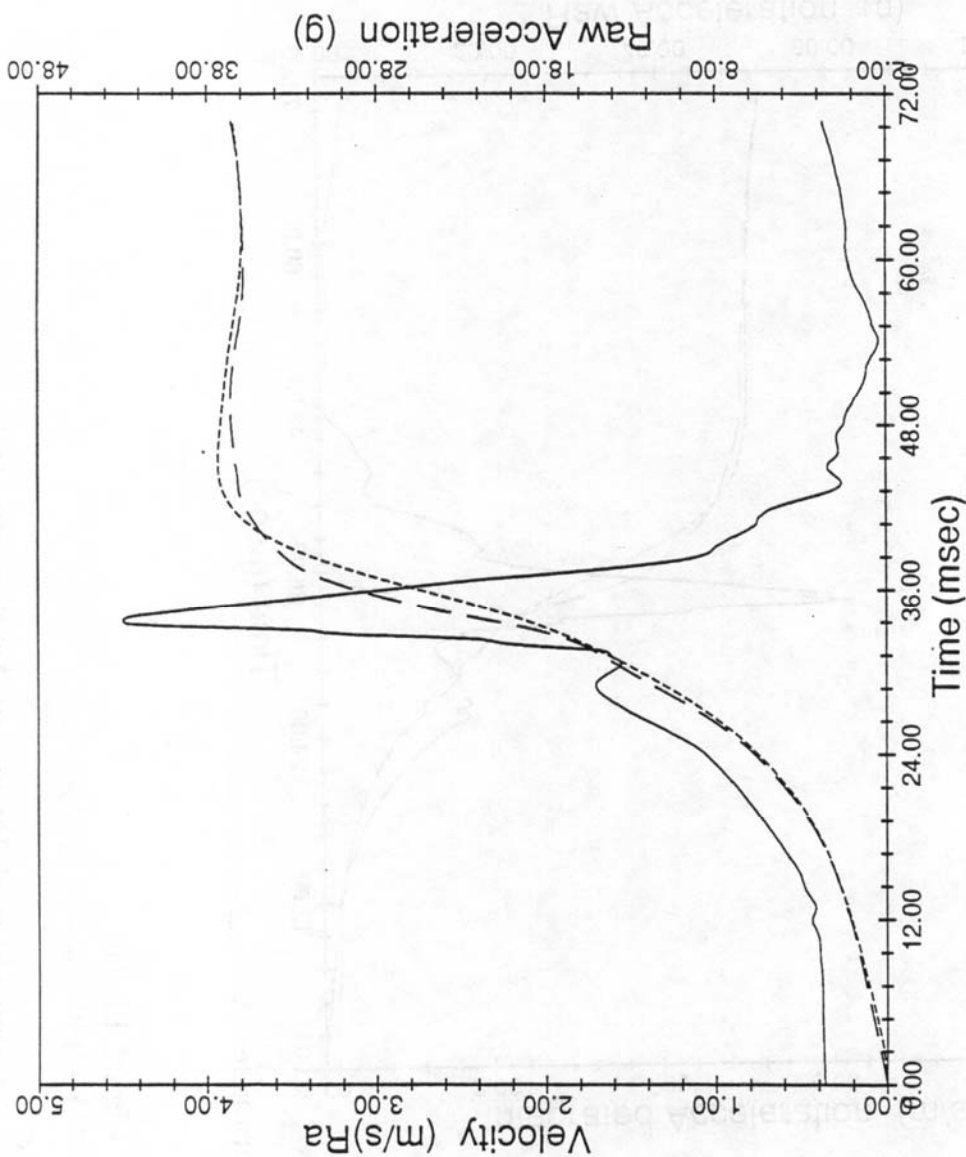


Figure 3. Comparison of Integrated Acceleration from Accelerometer A to the Velocity Computed From the Digital Linear Displacement Transducer Output

# ACCELEROMETER SHOCK CALIBRATION



Acceleration from Accelerometer B \_\_\_\_\_

Integrated Acceleration - - - - -

Velocity Computed from Digital Linear Displacement Transducer Output \_\_\_\_\_

Figure 4. Comparison of Integrated Acceleration From Accelerometer B to the Velocity Computed From the Digital Linear Displacement Transducer Output



# ACCELEROMETER SHOCK CALIBRATION

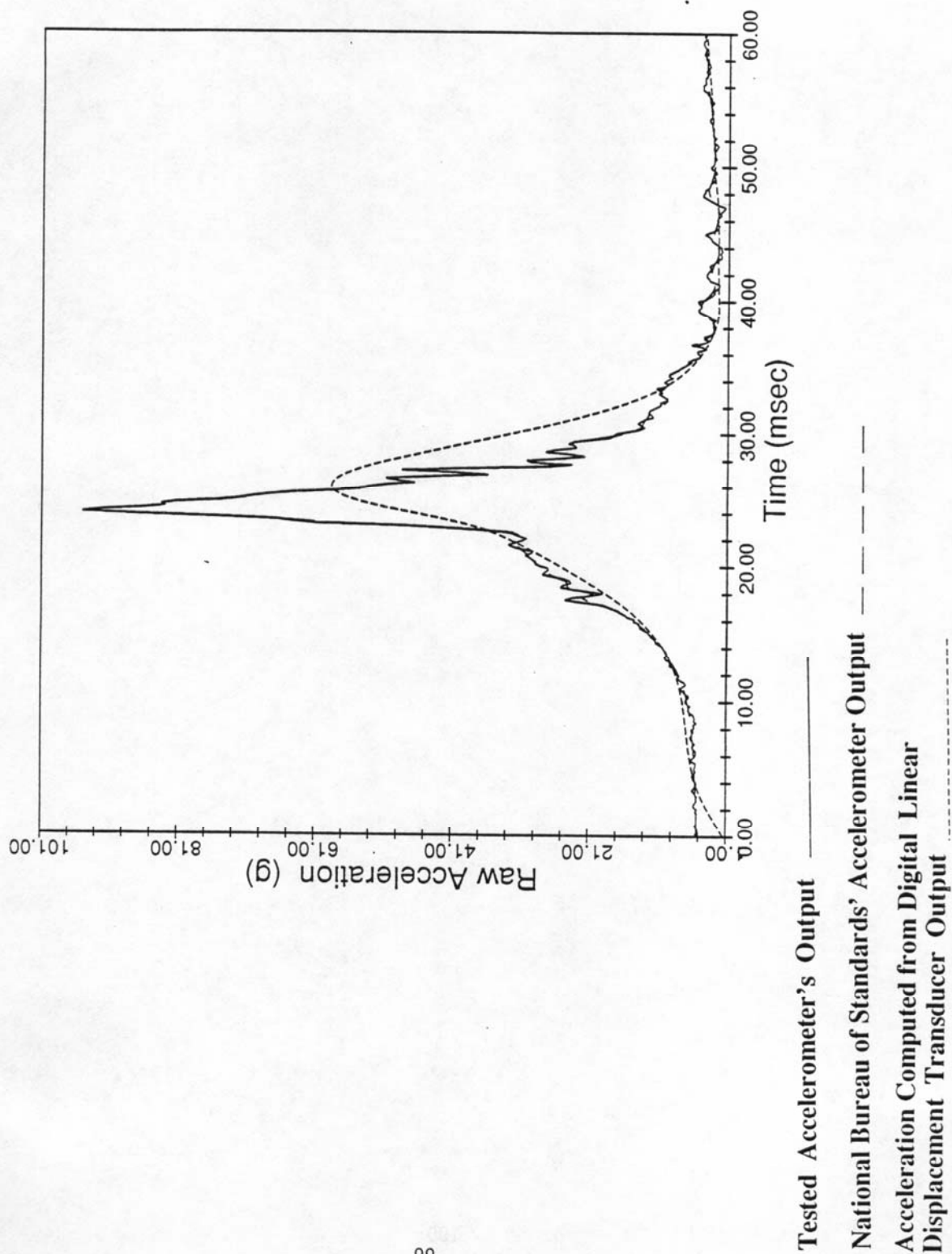
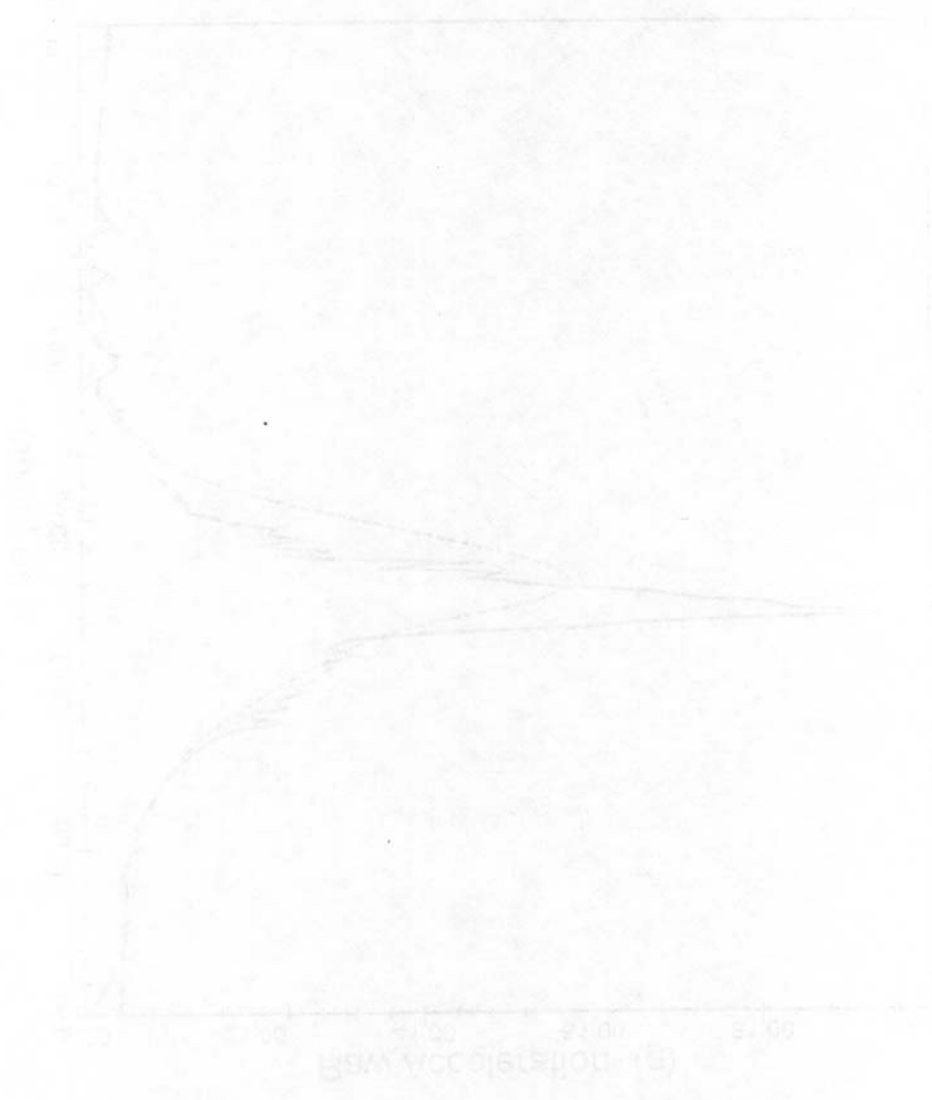


Figure 5. Comparison of Accelerations

Figure 10. A typical output voltage regulation curve.

The output voltage regulation curve is a plot of the output voltage versus the input voltage. The output voltage is measured at the output terminals of the power supply. The input voltage is measured at the input terminals of the power supply. The output voltage regulation curve is a plot of the output voltage versus the input voltage. The output voltage is measured at the output terminals of the power supply. The input voltage is measured at the input terminals of the power supply.



## DISCUSSION

PAPER: Accelerometer Shock Calibration

SPEAKER: G.S. Nusholtz

Q: Unidentified

Guy, did I understand you when you were saying you needed greater sensitivity on the time rather than on the displacement measuring capability? It would seem to me that when you're trying to get from displacement to acceleration you have two sensitivities to worry about, time and your length, the smallest increment of length that you can measure off your LDVT, in terms of accuracy, and if I had an error if I could only measure plus or minus a tenth of an inch discrimination of length even if I went three megahertz time sampling I still would have that data error in the signal.

A: That is correct. What I would have to do, what I think I have to do is increase the signal the amount, no decrease the amount of displacement. Right now it's ten thousandth of an inch so if I wanted to get the acceleration correct I'd have to go down to a thousandth of an inch. But it would put out a spike so quickly at say 6 meters per second that I'd never be able to see it when I digitized it.

Is that what you're asking or am I addressing something else?

Q: When you have a particular signal and you have a deviation from it how do you know it's deviating in time and not in your length measurement? One of your signals you try to overlay two together and you had an error, a mismatch between the two.

A: Correct.

Q: I thought I got from your talk that you were attempting to say that you had to cut your time step down in order to get a better characterization?

A: No. No. You have to increase your time step in digitizing.

Q: I understand that, but you didn't make mention about your length measurement of your displacement transducer. Why did you focus in only on time and not on the length?

A: I'm a little confused. What do you mean, length, in what regard?

Q: You were measuring a displacement with a LDVT, which had a certain minimum discrimination. If I would have that down, I

would also get a more accurate signal coming out. Did I understand you to say you only wanted to increase your time sampling?

A: You have to do both.